Fuzzy Logic Particle Tracking

A new all-electronic Particle Image Velocimetry technique that can efficiently map high-speed gas flows has been developed in-house at the NASA Lewis Research Center. Particle Image Velocimetry is an optical technique for measuring the instantaneous two-component velocity field across a planar region of a seeded flow field. A pulsed laser light sheet is used to illuminate the seed particles entrained in the flow field at two instances in time. One or more charged coupled device (CCD) cameras can be used to record the instantaneous positions of particles. Using the time between light sheet pulses and determining either the individual particle displacements or the average displacement of particles over a small subregion of the recorded image enables the calculation of the fluid velocity. Fuzzy logic minimizes the required operator intervention in identifying particles and computing velocity.

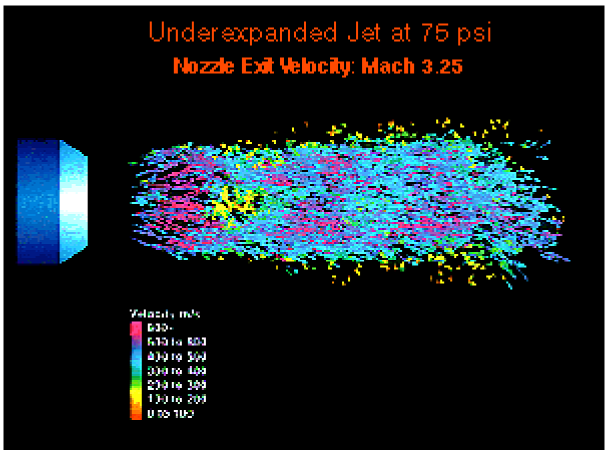
Using two cameras that have the same view of the illumination plane yields two single-exposure image frames. Two competing techniques that yield unambiguous velocity vector direction information have been widely used for reducing the single-exposure, multiple-image frame data: (1) cross-correlation and (2) particle tracking. Correlation techniques yield averaged velocity estimates over subregions of the flow, whereas particle tracking techniques give individual particle velocity estimates.

For the correlation technique, the correlation peak corresponding to the average displacement of particles across the subregion must be identified. Noise on the images and particle dropout result in misidentification of the true correlation peak. The subsequent velocity vector maps contain spurious vectors where the displacement peaks have been improperly identified. Typically these spurious vectors are replaced by a weighted average of the neighboring vectors, thereby decreasing the independence of the measurements.

In this work, fuzzy logic techniques are used to determine the true correlation displacement peak even when it is not the maximum peak, hence maximizing the information recovery from the correlation operation, maintaining the number of independent measurements, and minimizing the number of spurious velocity vectors. Correlation peaks are correctly identified in both high and low seed density cases. The correlation velocity vector map can then be used as a guide for the particle-tracking operation. Again fuzzy logic techniques are used, this time to identify the correct particle image pairings between exposures to determine particle displacements, and thus the velocity (see figure). Combining these two techniques makes use of the higher spatial resolution available from the particle tracking. Particle tracking alone may not be possible in the high seed density images typically required for achieving good results from the correlation technique. This two-staged velocimetric technique can measure particle velocities with high spatial resolution over a broad range of seeding densities.

The data shown in the figure are from a two-camera setup where each camera records a single exposure of the particle-seeded flow illuminated by a neodymium:yttrium aluminum garnet (Nd:YAG) laser light sheet pulse. The time between exposures was 500 nsec. A convergent nozzle was operated at a plenum pressure of 75 psi, generating an underexpanded jet flow with an exit velocity of Mach 3.25. A Mach disk can be seen in the flow, approximately 1.5 nozzle diameters downstream of the nozzle exit plane. Approximately 3000 velocity vectors have been identified in the flow. The velocity vector density was so high that a pseudovelocity-contour plot was created by color coding the vector magnitudes.

Particle-tracking velocity vector map of an underexpanded nozzle flow. Pressure, 75 psi; nozzle exit velocity, Mach 3.25.



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